attainable classical coefficient of diffusion of ions on localized particles [10], $D_c \sim \varepsilon_t^2 \varepsilon^{-1/2} cT/eB$, where $\varepsilon_t = a/R$ is the ratio of the minor radius of the plasma to the radius of curvature (from the condition that there be no disruption of the magnetic surfaces by the curvature it follows that $\varepsilon_t < \varepsilon^2$). In addition, unlike the classical diffusion on localized particles, the turbulent diffusion considered here involves all the ions to an equal degree, and it is therefore insensitive to the formation of a plateau on the distribution function in the region of the localized ions, which leads to a lowering of $D_c$ when the collision frequency is decreased [9].


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## DETERMINATION OF THE LEVEL WIDTHS OF GAS MOLECULES BY THE PHOTON-ECHO METHOD


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Submitted 16 June 1969
ZhETF Pis. Red. 10, No. 2, 105 - 108 (20 July 1969)


In analogy with spin echo [1], the photon-echo phenomenon is used successfully to determine the relaxation times in a solid [2] and the collision widths of the levels of gas molecules [3, 4]. The photon-echo method is useful also for the determination of the g-factors of levels [5] and other characteristics of gas molecules [6, 7]. So far, however, the photon-echo method was used only to measure the sum of the widths of the upper and lower resonance levels by exciting the gas with two light pulses.

We demonstrate in this paper the possibility of measuring the width of each resonance level separately by the photo echo method. To this end, the gas medium must be excited by three light pulses and the photon echo produced by the second and third pulses must be investigated. The level widths are determined from the attenuation of the intensity of this photon echo as a function of the time interval between the transmitted pulses. The greatest effect is reached when the first, second, and third excited pulses are respectively 180, 90, and 180 degree pulses, and all move in the same direction.

For concreteness, we consider the photon echo in a gas for an atomic transition with change of total angular momentum $1/2 \rightarrow 1/2$. The basic equations are chosen to be the

D'Alambert equation and the equation for the density matrix with allowance for the relaxation terms and level degeneracy.

Assume that at the instant $t = 0$ a linearly polarized of duration $T_1$, in resonance with the given atomic transition, is incident on a medium with a Maxwellian velocity distribution of the molecules (atoms). After the first exciting pulse has passed, the induced polarization current $j(v)$ of a group of molecules moving with velocity v attenuates in time like $\exp[-(\gamma_1 + \gamma_2)t/2]$, where $\hbar\gamma_1$ and $\hbar\gamma_2$ are the widths of the lower and upper levels, and the retardation effect is taken into account everywhere by means of the substitutions $t \to t - z/c$. The macroscopic polarization current $\int j(v)dv$, owing to the random motion of the molecules, decays much more rapidly, like

$$\exp[-t^2/T_0^2 - (\gamma_1 + \gamma_2)t/2],$$

where $\hbar/T_0$ is the Doppler width of the level ($1/T_0 \gg \gamma_1 + \gamma_2$). Unlike the photon echo with two exciting pulses, it is necessary to take into account here the distribution of the atoms over the sublevels, and the law governing the attenuation of the density matrices $\rho_1$ and $\rho_2$ with time for both the upper and lower levels, respectively,

$$\rho_2 \sim \exp(-\gamma_2 t), \quad \rho_1 = c_1 \exp(-\gamma_1 t) + c_2 \exp(-\gamma_2 t),$$

where $c_1$ and $c_2$ are constant matrices.

At the instant of time $t = \tau_1 \gg T_1$, a second exciting pulse of duration $T_1 \ll \tau_1$ in the same direction, with a polarization vector that makes an angle $\psi_1$ with the polarization of the first pulse. As a result of the phase synchronization of the individual emitters at the instant $t = 2\tau_1$ a primary photon echo is produced, with an intensity proportional to

$$\sin^2\Omega_1 T_1 (1 - \cos\Omega_2 T_2)^2 \exp[-2(\gamma_1 + \gamma_2)\tau_1] \tag{1}$$

and with polarization at an angle $2\psi_1$ to the polarization of the first pulse. Here $\Omega_i^2 = \gamma c a_i^2/\hbar\omega$, where $\gamma$ is the probability of the spontaneous emission of the quantum $\hbar\omega$, $a_i$ is the amplitude of the vector potential of the i-th transmitted pulse of light of frequency $\omega$, and $(\Omega_i T_0)^2 \gg 1$. The sum of the widths $\hbar\gamma_1 + \hbar\gamma_2$ of the two excited resonance levels is determined from the attenuation of the intensity of the primary photon echo.

To determine the width of the lower and upper levels $\hbar\gamma_1$ and $\hbar\gamma_2$ separately, it is necessary to send into the medium first an 180° pulse $\Omega_1 T_1 = \pi$, and then a 90° pulse $\Omega_2 T_2 = \pi/2$. Then the primary echo (1) is not produced. To produce a photon echo in this case, it is necessary to send at the instant $t = \tau_2$ a third exciting pulse of duration $T_3$ and with a polarization vector making an angle $\psi_2$ to the polarization of the second pulse. After passage of the third pulse, at the instant $t = 2\tau_2 - \tau_1$, a photon echo is produced with a polarization directed at an angle $2\psi_2$ to the polarization of the second pulse, and with an intensity proportional to

$$\left[\left(1 + \frac{2\gamma}{\gamma_2}\right) e^{-\gamma_2 \tau_1} - \left(\frac{n_2}{n_1} + \frac{2\gamma}{\gamma_2}\right) e^{-\gamma_1 \tau_1}\right]^2 e^{-2(\gamma_1+\gamma_2)(\tau_2 - \tau_1)}, \tag{2}$$

where $n_1$ and $n_2$ are the densities of the active molecules at the lower and upper levels, due to the Boltzmann distribution. The factor preceding expression (2) in the formula for the intensity of the photon echo has not been written out in explicit form, since it is independent of $\tau_1$ or $\tau_2$. This factor is maximal when the third pulse is a 180° pulse. By measuring the intensity of the photon echo from the three pulses as a function of $\tau_1$ and $\tau_2$, and knowing the sum $\gamma_1 + \gamma_2$ obtained from the damping of the primary echo (1), we can easily determine with the aid of (2) the values of $\gamma_1$ and $\gamma_2$ separately.

If $n_2 \ll n_1$ and $\gamma \ll \gamma_2$, then the characteristic factor (2) takes the simple form

$$\exp\{2[-\gamma_2 r_2 - \gamma_1(r_2 - r_1)]\}. \tag{3}$$

The obtained polarization effects make it possible to separate relatively simply the exciting pulses from each other and from the photon echo, which entails great difficulties when the polarization of the photon echo coincides with the polarization of the transmitted pulses. It suffices to this end to put $\psi_1 = \psi_2 = \pi/4$, and then the polarization vectors of all three pulses and of the photon echo form a fan of four vectors, inclined to each other at an angle $\pi/4$.

We have considered above the photon echo (2) produced by the second and third exciting pulses. If the first pulse is not a 180° pulse, then a photon echo is produced by the primary photon echo and the third exciting pulse, as well as a photon echo due to the first and third transmitted pulses. Their intensity, however, does not contain the factor (2) and therefore does not make it possible to determine $\gamma_1$ and $\gamma_2$ separately.

To determine $\gamma_1$ and $\gamma_2$ it is possible, in principle, to use also multiple photon echo in a gas, produced after the passage of two excited pulses. However, the intensity of the multiple echo is much weaker, and this affects the measurement accuracy.

The polarization features of the photon echo in other atomic transitions differ from those considered above. A change takes place also in the pre-exponential factors in (2), but in the region $n_2 \ll n_1$ and $\gamma \ll \gamma_2$, the characteristic factor (3) remains in force for the atomic transitions $1 \nleftrightarrow 0$, $1 \to 1$, and $1/2 \nleftrightarrow 3/2$.

The authors are grateful to V. M. Galitskii for a discussion.

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